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Contractors Water Authority

BEFORE THE STATE WATER RESOURCES CONTROL BOARD

OF THE STATE OF CALIFORNIA AND THE CENTRAL VALLEY

REGIONAL WATER QUALITY CONTROL BOARD

In the Matter of **Salinity Workshop January 31, 2006**	**TESTIMONY OF SAN JOAQUIN RIVER EXCHANGE CONTRACTORS WATER AUTHORITY: TESTIMONY OF CHRIS WHITE, P.E.** Hearing Date: January 31, 2006

1.0 My name is Chris White, and I am a Registered Civil Engineer (California RCE 48073, August 1991). Since 1977 I have worked within the region that includes the service area of the San Joaquin River Exchange Contractors Water Authority on issues relating to irrigation and drainage. For the last 11 years, I have served as District Engineer (1993 to today), and then General Manager (2000 to today) of the Central California Irrigation District. My educational and work experience is set forth on **SJREC-1**.

2.0 The San Joaquin River Exchange Contractors Water Authority ("Exchange Contractors") serves an area of approximately 240,000 acres lying adjacent to the San Joaquin River in the area from the City of Mendota at the South and extending northward approximately 80 miles to Crows Landing. The largest proportion of the service area consists of Central California Irrigation District approximately 145,000 acres, Firebaugh Canal Water District consisting of approximately 22,000 acres, and San Luis Canal Company consisting of approximately 47,000 acres. The Districts are situated on the West side of the San Joaquin River, and have sustained irrigated agriculture since the 1880s. A portion of the Districts lie downslope and adjacent to the irrigated areas of the San Luis Unit of the Central Valley Project. **SJREC-2** is a map of the Exchange Contractors service area, and **SJREC-3** is a map showing the areas of the San Luis Unit relative to lands within the Exchange Contractors service area.

3.0 The Exchange Contractors receive water service primarily from the Delta-Mendota Canal in exchange for our historic rights to San Joaquin River water, and all of the CCID, SLCC and FCWD drain into the San Joaquin River.

<u>I would make the following points to you and hopefully provide convincing testimony to support these points:</u>

3.1 The Exchange Contractors and adjacent CVP Contractor lands within Panoche, San Luis, Pacheco and Westlands Water Districts do have a plan and are implementing that plan regarding salinity. More than $60 million has been invested in capital facilities, primarily by the local water agencies, and more than $1 million per year currently is invested by these agencies in operations to retain salts and to manage salts. Another $60 million is needed by 2009. Your Board can and should allocate all or a portion of this money from Proposition 50 funds. The local agencies will continue to invest funds for capital and operations, but insufficient funds exist to complete the project in time, and this is where we need your help.

3.2 Even with these expenditures, it is not possible to get the salt out of the San Joaquin River and render it a pristine Sierra river because of groundwater accretion into the river. The regulations and requirements of the SWRCB, Regional Board and particularly the 2 part per billion selenium standard for waters that may come in contact with waterfowl are now retarding and confusing progress, not stimulating action. The SWRCB and Central Regional Valley Board should modify some of their TMDL's and Water Quality Control Plan Standards and help us implement feasible measures. If done properly, these feasible measures can be used to actually meet and/or exceed water quality standards.

3.3 The Exchange Contractors are continuing to litigate against the Bureau regarding drainage requirements, but the effect has been to drive the Bureau into counter-productive positions and to label the drainage problem as another example of California craziness. The drainage problem was in fact partially caused by the State not moving forward with participation in the Drain at an early date. The National Academy of Sciences is now predicting loss of more than 1 million acres of productive farm land. There is enough blame to go around; however, blame will not bring us closer to meeting water quality regulations. What we need is leadership and money now.

4.0 The establishment of salinity standards at Vernalis which simply express a longing for a pristine San Joaquin River, rather than recognizing that a man-altered river exists, and is being utilized by the Bureau and SWP as a drainage system instead of the San Luis Drain, are not only unrealistic, they are destructive to the efforts that in fact can be accomplished to manage salinity and to preserve the beneficial uses of the San Joaquin River. A salt standard of .7 mmhos/cm EC, especially if adopted as the basis for TMDL loads at upstream points is not necessary to protect beneficial uses. The harm of the stringent standards is that they (a) destroy beneficial uses of water and valuable farm land by encouraging salt to be deposited in ground water or retained on the farms, eventually destroying the area, and (b) force farmers to remove good quality tailwater from the river, leaving behind only accretion flow. Such a scenario will degrade the quality of water in the river to 3,000 to 5,000 TDS.

5.0 The concept of a Water Quality Control Plan for salinity is fatally flawed if the Board simply sets a numerical standard for salinity in which upstream agricultural users are driven to remove surface drainage from the San Joaquin River during the whole irrigation season. The approach will result in the management of drainage flows only temporarily and will soon devolve into un-managed poor quality drainage from shallow groundwater and the destruction of our productive farm land.

6.0 The Westside Regional Drainage Plan is a means of providing for salinity management of the area where poor quality drainage water appears and can pass from subsurface flows into the San Joaquin River. It is consistent with and easily integrated into an out-of-valley export system which would collect drainage waters from other areas. It requires the United States and State of California to fund $90 million of further facilities and to fund the operation and maintenance costs of a reverse osmosis plant which would treat 4,000 ac ft of drainage flows which is a reduction from approximately 40,000 acre feet of drainage flows per year which were flowing into the San Joaquin River in 1996. Some of your Board Members may not be fully acquainted with the following facts:

7.0 The San Luis Act requires that a drainage system be constructed and operated by the Bureau as a part of its operation of the San Luis Unit. For a variety of reasons, the Bureau has not complied with this requirement. One the principal reason was that the State of California, which was planned to participate in the costs of the San Luis Drain and to extend it southward to collect drainage from the Tulare Basin area and Kern County, refused to bear its part of the drainage cost and in fact became an opponent of the discharge into the San Francisco Bay, refusing to issue the necessary permits. The National Academy of Sciences, the foremost scientific body of this nation, published a report in October of 2005 which predicts the loss of farming productivity and use, groundwater resources which are depended upon by urban residents, and the perpetual use of the San Joaquin River for un-managed salt exports because the project as originally designed and authorized has not been completed. A copy of that report is attached as **SJREC- 4.**

8.0 The San Luis Unit's irrigated lands lie adjacent to the Central California Irrigation District, Firebaugh Canal Water District and San Luis Canal Company. **SJREC-3** depicts this area.

9.0 As a result of the Bureau of Reclamation's failure to provide drainage to the San Luis Unit, poor quality subsurface drainage water from the San Luis Unit and the downsloope Camp 13 area of Central California Irrigation District and Firebaugh Canal Water District, is discharged to the San Joaquin River.

10.0 The California Aqueduct is routed through the area lying above the Exchange Contractors, Panoche Water District, San Luis Water District and Pacheco Water District drainage impacted lands. The State Water Contractors and Southern California depend upon this conveyance canal for water service. All canals leak. That leakage was known and anticipated. The potential impact upon drainage conditions in the downslope areas was also known and anticipated. This is one of the reasons that the SWP was to participate in the construction and operation costs of the San Luis Drain to the San Francisco Bay in the area of Antioch. When the SWP contractors elected not to participate in and complete the San Luis Drain with the Bureau, the SWP did not install wells to put the leakage back into the California Aqueduct. **SJREC-5** is a copy of a recent report which estimates that leakage adding to groundwater pressures and downslope migration in the area above the participants in the Westside Regional Drainage Plan, including areas of the San Luis Unit, are at 5,730 ac ft/year to 7,100 ac ft per year from the State Aqueduct. For 40 years (1966 through 2005) no ameliorative actions have been taken by the SWP to recapture this water which now amounts to 230,000 to 300,000 ac ft. Yet the SWP, at your recent Cease and Desist Hearings, argued that it had no role in causing or curing the salinity conditions of the areas draining to the San Joaquin River.

11.0 The answer to solving water quality problems in the San Joaquin River is for Reclamation, with monetary contributions from the State of California, to provide drainage to the San Luis Unit and our adjacent area. Such a plan, the Westside Regional Drainage Plan, has been developed and is based on in-valley disposal. The plan is implementable, is technically feasible, and modeling shows that it is the key tool that can be used to meet Vernalis salinity standards.

12.0 Comments from time to time have indicated that some past Board members and staff have held out hope that the litigation brought by the Exchange Contractors against the Bureau would eventually lead to a solution. In fact the Exchange Contractors have diligently pursued litigation, but this Board must remember that no Federal Court can compel the United States to appropriate money and that litigation and California politics can drive what might be an otherwise constructive United States government to absolutely counter-productive positions. One of the most current examples is exemplified by the following: In 2004, even though the Central Valley Project Act itself requires that drainage be provided to the San Luis Unit, the United States and CVP Contractors, citing provisions of the California Water Code, argued to Judge Wanger that neither the United States nor its CVP Contractors can be responsible for the monetary damages from a continuing nuisance caused by drainage waters entering or appearing within the Exchange Contractors service area.

12.1 The Firebaugh Canal Water District's predecessor and CCID went to Federal Court in 1963 and again in 1968 to require that the Bureau build and operate its drainage system for the San Luis Unit as the San Luis Act requires. Each time the Court refused an injunction on the grounds that the Bureau promised that the export system out of the Central Valley would be constructed and operated. It was never constructed and operated. Only a collector system for some 42,000 acres was constructed, and that water was delivered only to Kesterson. That system was shut down in 1986.

12.2 In 2000, finally the 9th Circuit in the case of *Firebaugh v. United States* ordered the Bureau to provide for construction and maintenance of a drainage system for the San Luis Unit. The Court gave the Bureau the option to consider and implement other options than the physical San Luis Drain to the Bay, and unfortunately, this has caused the Bureau to delay taking any action. Since 1985, on the 42,000 acres, and since the early 1970s as to the remaining approximately 200,000 acres, the Bureau is operating what we refer to as its "Stealth Drainage System" in which drainage of poor quality water eventually reaches the San Joaquin River either as surface drainage or as groundwater accretion flows.

12.3 In 2000, in its Decision 1641 (the Bay Delta Decision) rendered in 2000, the SWRCB Board ordered that by April of 2005, the Bureau provide to the SWRCB its plan for implementing the drainage system. A plan would seem to require financing. The Bureau has not provided any reports to your Board. We have asked previously that this Board enforce its Decision 1641 Order and obtain progress reports and commitments.

12.4 Against this backdrop, the SWRCB and its Central Valley Regional Water Quality Control Board can continue to adopt salinity, boron and selenium standards at

Vernalis and at upstream locations, the Regional Water Quality Control Board can pretend that the Bureau's "Stealth Drainage System" in fact is not utilizing the San Joaquin River as a drain, and ignore the fact that although the flow of salinity through this River system and the tributaries can be managed to protect all beneficial uses, it cannot be stopped, and attempt through regulatory standards to demand .7 mmhos/cm EC at Vernalis and above, which is unnecessary but also unrealistic and counter-productive.

13.0 There is a common belief among regulatory agencies that if they simply tighten standards the worker bees (the citizens) will find a solution. In November, you adopted two TMDL's one for salt and boron at Vernalis and a second for Dissolved Oxygen. We pointed out that ordering us to not remove any water which would reduce flows through the Stockton Ship Channel was inconsistent with ordering us to reduce the drainage flows that include algae and also inconsistent with ordering us to reduce salinity in drainage since there is no means of separating the salinity from the drain water which is desirable to maintain flows in the River. With an understanding of the Westside Regional Drainage Plan, you can see the inconsistency and contradiction of these regulatory requirements even more clearly. Since 1996, the region has reduced the drainage flow volumes from approximately 100,000 acres irrigated from 60,000 ac ft to approximately 30,000 ac ft (Testimony of Joseph McGahan, Cease and Desist Order Proceeding). Between now and 2009, the Westside Regional Drainage Plan, to comply with your Basin Plan requirement of no more than 2 parts per billion of selenium in channels frequented or used to irrigate waterfowl habitat and your discharge permit requirements for the Grassland Bypass Project, will require the total removal of that drainage flow. This violates your D.O. TMDL. Now focus on the proposed reverse osmosis plant which requires state and federal funding, which funding cannot be provided if it would violate a TMDL. The clean water which exits the reverse osmosis plant must be sold for urban uses to recover the extreme expense of treatment and disposal of the residue. The D.O. TMDL prohibits a project which diverts that water to those purposes.

13.1 We and others have asked that you reconsider the TMDL's for salt and boron at Vernalis and the D.O TMDL. If you do not, are we to take that as direction? Are we to stop reducing drainage flows to the River to maximize dissolved oxygen even though they contain salt and boron? Are we to not pursue the Westside Regional Drainage Plan? Would you prefer that we allow the Bureau to continue its expenditure of millions of dollars per year for the study of the drainage solution rather than that those sums be directed to implementing meaningful management facilities? Would you prefer that we all pretend that your regulations will "clean up the San Joaquin River quality" knowing full well that those salts removed simply will pollute the underground aquifers and through the shallow aquifers accrete to the San Joaquin River flows in any case, resulting in the destruction which the National Academy of Sciences describes?

14.0 We believe that a better plan exists, and the key is your rejection of the fiction that by implementing regulatory requirements and standards the SWRCB and Regional Board will somehow prevent the use of the San Joaquin River by the Bureau as a "stealth drain". The steps in that "better plan" are as follows:

14.1 Reject the idea that by establishing stringent standards for salt at Vernalis and upstream (standards that are not necessary to productively continue agricultural use in the South Delta) you can return the San Joaquin River to a pristine natural stream. As an example, 1.1 mmhos/cm EC water is routinely applied for irrigation of crops within the Exchange Contractors, and with modern management and farming methods, no adverse effects on yields occur. As Dr. Burt explained in your Triennial Review hearings in March 2005, soil leaching and soil salinity management permit water of much higher salinity to preserve even the most salt-sensitive cropping. We submit that more consistent water quality is achievable at Vernalis through the implementation of a water quality management plan that contains all the elements contained in the Westside Regional Drainage Plan. We want to dispel the notion that if you adopt standards upstream of Vernalis, water quality will automatically be improved. To improve water quality will take projects such as we are proposing in the WRDP. This plan can be done with existing standards, and new and more stringent standards are counter-productive at this time.

14.2 Instruct your Regional Board that the mindless regulation of selenium, boron and salt will only have the effect of guaranteeing that the San Luis Unit farmers and the adjacent farmers within the Exchange Contractors are not the dischargers of these constituents.

14.3 Become the leader in preserving agricultural production by cooperatively implementing the "Westside Regional Drainage Plan." Convene a hearing and ask the State of California and Bureau to come before you and explain how this plan can be advanced and funded in time to meet the existing water quality standards.

15.0 The Westside Regional Plan cannot be effective unless it is recognized that establishing discharge permits for the Grassland Bypass Project, as an example, that require in 2009 that any water entering the San Joaquin River from Salt and Mud Sloughs, have no greater than 5-ppm selenium or no greater than the .7 mmhos/cm EC that the Regional Board seems to be patterning after your current standard at Vernalis as an upstream standard, is counterproductive and contrary to a managed drainage plan. The Westside Regional Drainage Plan will require time to develop and be effective. All those premature requirements will do is require that we stop all drainage, salt up the land in this area, pack the shallow groundwater with selenium, boron and salt-enriched water which will accrete and flow into the San Joaquin River over a period of years in a totally uncontrolled fashion, and do so long after your requirements have destroyed the productivity of our lands.

16.0 <u>So what should this Board do in regard to establishing the Salinity Standard in the South Delta?</u>

16.1 Indicate that you understand that the San Joaquin has a number of beneficial uses, including both irrigation and drainage, and that since for the last 40 years drainage water has entered the soil profile and is migrating downstream both in the forms of pressure and physical water, that the salinity standards have to recognize the inevitability of poor-quality drainage water flowing into the San Joaquin River for a number of years. Adopt a management plan that provides assurance that reasonable and beneficial uses will be protected at Vernalis during the irrigation season. Grant reconsideration of the two TMDL's adopted in November of 2005.

16.2 Order the Bureau, in conformance with your Decision 1641, to come before you immediately and explain whether they have a different plan than the Westside Regional Drainage Plan that the local interests, out of desperation and the Bureau delay, have developed. Ask the SWP to appear and explain its plan to participate and fund or its alternatives for recapturing the 300,000 acre-feet it has leaked and contributed. Ask for assurance of financial contributions to the implementation of that drainage plan immediately by both the United States and the State of California.

16.3 The Grassland Bypass Drainage Plan, which currently collects and segregates the worst quality waters, is facing a requirement that all collected waters be removed from Mud and Salt Sloughs by 2009 because the drainage water selenium exceeds 2 ppb. If the Regional Board adopts a standards of .7 mmhos/cm EC at upstream locations, taking its cue from you, even though this standard is not necessary and does not in any way protect irrigation use as a beneficial use, all local attempts to try to fill in for the Bureau's inaction will be doomed, and more, not less, saline conditions can be expected at Vernalis due to uncontrolled drainage and accretion flows.

16.4 Become a leader and an organizer, and sublimate the instinct to imagine simple solutions as achievable through regulation of those who have little control and even less money. Explain to your Regional Board and implement yourself in the review of the Regional Board regulatory activities, including TMDL's and establishment of upstream standards, the principle that establishing water quality plan standards based on a longing that the San Joaquin River be returned to a pristine natural stream is not reality, and it is not necessary to preserve beneficial uses. Recognize in your plan for the Southern Delta that attempts to regulate, ignoring that this is a managed waterway accommodating both irrigation and drainage uses will be counterproductive, destroying the beneficial use of the Exchange Contractors farm land, and destroying the efforts to manage the release of drainage water to the San Joaquin in periods and manners in which the least risk of impairment of beneficial uses will occur.

If called to testify in this matter, I could and would testify to each of the above matters, except as to those matters stated upon information and belief, and as to those matters I believe them to be true and correct.

Executed this 20th day of January, 2006 at Los Banos, California.

/S/ ______________________
CHRIS WHITE, P.E.

STATEMENT OF QUALIFICATIONS

CHRIS WHITE
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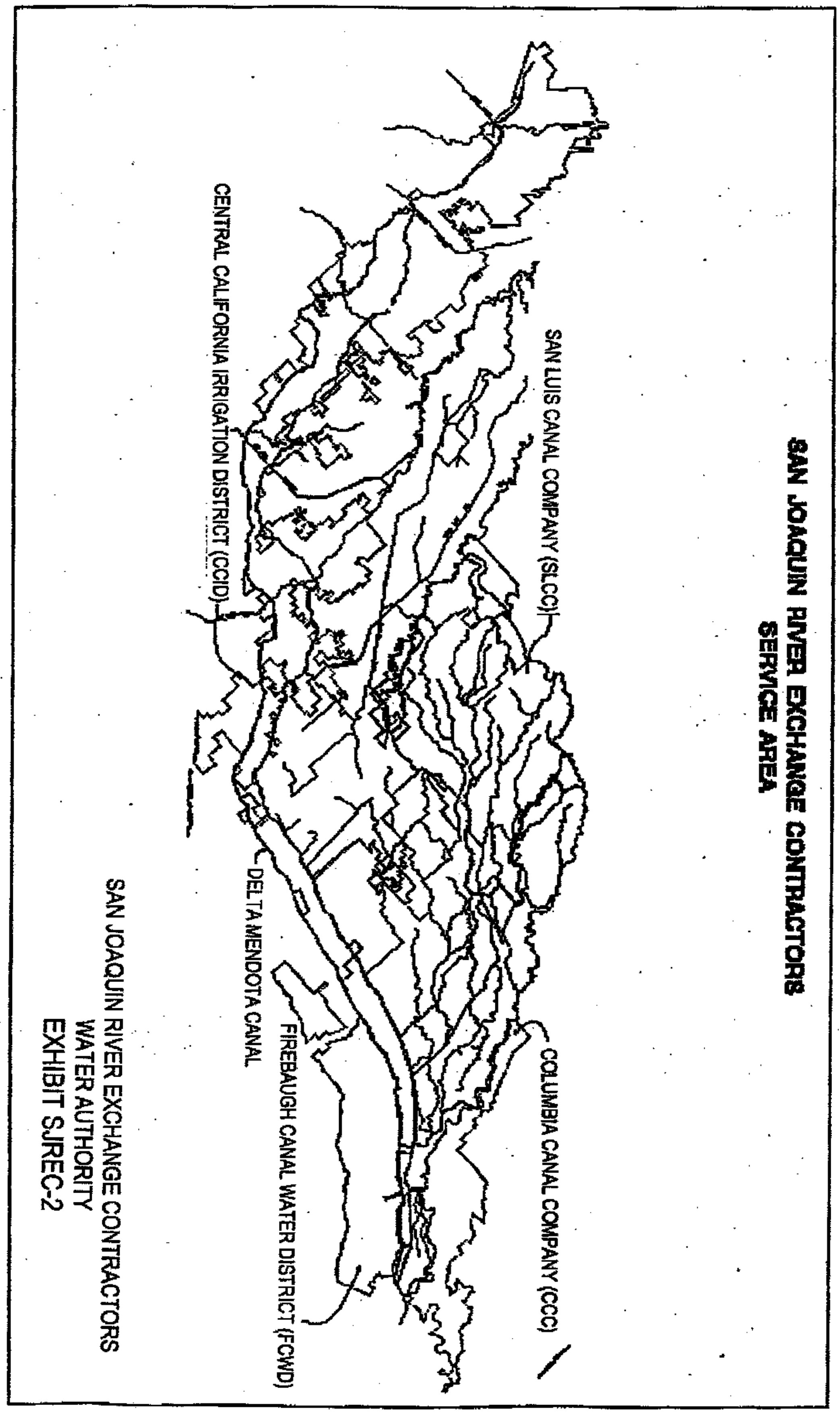
Professional Qualifications: Registered Civil Engineer and Licensed Land Surveyor, California.

1995 to Present: Assistant Manager and District Engineer, Central California Irrigation District, Los Banos, California, a member agency of the San Joaquin River Exchange Contractors Water Authority (Exchange Contractors).

1993 to 1995: District Engineer, Central California Irrigation District.

1991 to 1993: Project Engineer and Vice President, Stoddard and Associates, Los Banos, California.



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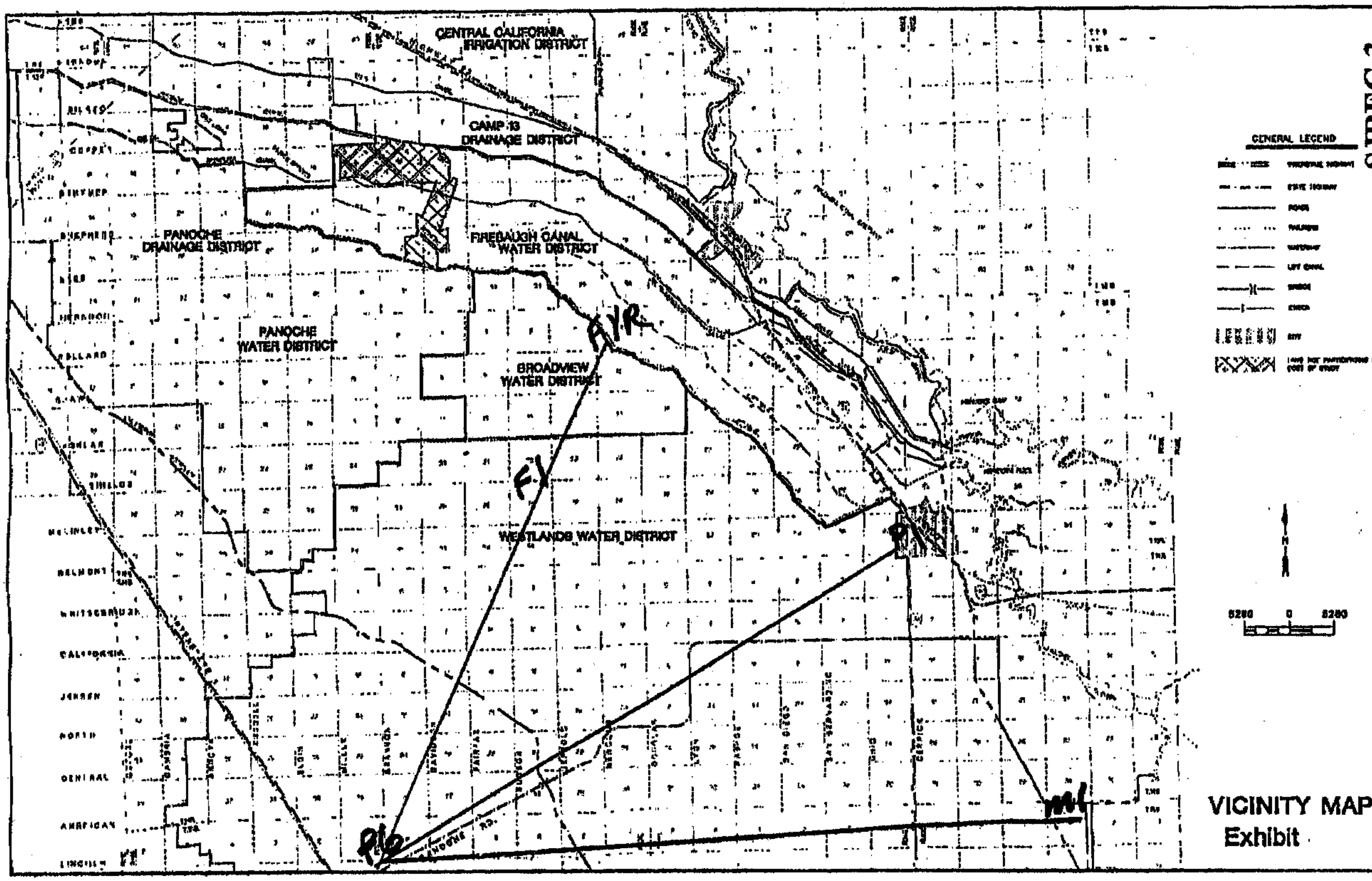

SAN LUIS UNIT'S IRRIGATED LANDS UPSLOPE OF CCID, FCWD and SLCC

Sustainability of irrigated agriculture in the San Joaquin Valley, California

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The sustainability of irrigated agriculture in many arid and semiarid areas of the world is at risk because of a combination of several interrelated factors, including lack of fresh water, lack of drainage, the presence of high water tables, and salinization of soil and groundwater resources. Nowhere in the United States are these issues more apparent than in the San Joaquin Valley of California. A solid understanding of salinization processes at regional spatial and decadal time scales is required to evaluate the sustainability of irrigated agriculture. A hydro-salinity model was developed to integrate subsurface hydrology with reactive salt transport for a 1,400-km² study area in the San Joaquin Valley. The model was used to reconstruct historical changes in salt storage by irrigated agriculture over the past 60 years. We show that patterns in soil and groundwater salinity were caused by spatial variations in soil hydrology, the change from local groundwater to snowmelt water as the main irrigation water supply, and by occasional droughts. Gypsum dissolution was a critical component of the regional salt balance. Although results show that the total salt input and output were about equal for the past 20 years, the model also predicts salinization of the deeper aquifers, thereby questioning the sustainability of irrigated agriculture.

regional hydrology | salinization | vadose zone

Salinization affects ~20–30 million hectares (ha) of the world's current 260 million ha of irrigated land (1, 2) and limits world food production (3). Salinity reduces water availability to plants (4) by the accumulation of dissolved mineral salts in waters and soils due to evaporation, transpiration, and mineral dissolution. Subsequent salt leaching leads to salt buildup in both shallow groundwater below the plant root-zone (RZ) and deeper groundwater bodies (aquifers). The San Joaquin Valley, which makes up the southern portion of California's Central Valley, is among the most productive farming areas in the United States. However, salt buildup in the soils and groundwater is threatening its productivity and sustainability.

Currently, there is a good understanding of the fundamental soil hydrological and chemical processes (5) that control soil and groundwater salinity. Much of this understanding was achieved by using modeling approaches that consider the hydrology and soil chemistry separately, that assume simplified steady-state flow for spatial scales not larger than the field, and that only consider the RZ. However, recent research (6–11) has shown that soils must be fully coupled with the vadose zone and groundwater systems for regional-scale studies, especially in areas where groundwater tables are shallow or groundwater pumping is used (12). Innovative predictive tools are needed that can be applied at the regional scale and at the long term, so that the sustainability of alternative management strategies can be evaluated. For this purpose, an integrated regional-scale hydro-salinity model was developed to fully couple the hydrology and salt chemistry of the vadose zone with the groundwater system. This model enables us to reconstruct historical changes in soil and groundwater salinization in general and for the western San Joaquin Valley in particular (13).

Historical Context

The study area represents a 1,400-km² irrigated agricultural region in western Fresno County on the west side of the San Joaquin Valley (Fig. 1*A*) and includes three alluvial fans. The alluvial soils are derived from Coast Range alluvium and are generally fine-textured (Fig. 1*B*). Irrigation water is managed by water districts for water distribution and drainage management. Details on the hydrogeologic setting, soils, and history of irrigation are published elsewhere (6, 14, 15) and are summarized in *Supporting Text* and Fig. 5, which are published as supporting information on the PNAS web site. Early irrigation in the valley, starting at the end of the 19th century, was limited to gravity diversions from the San Joaquin River and developed into intense groundwater pumping starting in the 1920s, leading to an increase in irrigated acreage westwards and upslope. After completion of the Central Valley Project and the State Water Project in 1953 and 1967, respectively, the whole study area was irrigated with high-quality imported water from the Sacramento Valley conveyed by the Delta-Mendota Canal and the California Aqueduct. These projects initially resulted in soil leaching of predevelopment salts. However, increased deep percolation rates combined with a sharp decrease in groundwater pumping resulted in a rise of the water table over much of the area (16). Since the mid-1980s the extent of saline-sodic soils has steadily migrated to the west, generally following the expansion of the shallow water table area [K. Arroues (2002), personal communication, Natural Resources Control Service, Hanford, CA].

The salinity problem on the west side of the San Joaquin Valley is partly attributed to the continuous presence of a low-permeability Corcoran clay layer (6), ranging in depths from ~30 m near the San Joaquin River in the east to a depth of ~250 m in the west, thereby largely defining the regional hydrology. To lower the water tables, subsurface drainage systems were installed to intercept and collect the shallow groundwater. Yet, soon thereafter it became eminently clear that drainage waters must be disposed off in an environmentally safe manner. Specifically, the 1983 discovery of migratory bird deaths and deformities was linked to elevated selenium levels in agricultural drainage water impounded in Kesterson Reservoir (17, 18). This finding led to an intensive investigation carried out jointly by federal and state agencies through the San Joaquin Valley Drainage Program (19). Current solutions include increasing irrigation efficiency, growing alternative salt-tolerant crops, drainage-water reuse, the collection of drainage water in evaporation ponds, land retirement, and increased groundwater pumping. However, for irrigated agriculture to remain sustainable, a soil salt balance must be maintained that allows for productive cropping systems.

Freely available online through the PNAS open access option.

Abbreviations: ha, hectares; Mton, million tons; RZ, root zone.

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SJREC-4
National Academy of Sciences Report

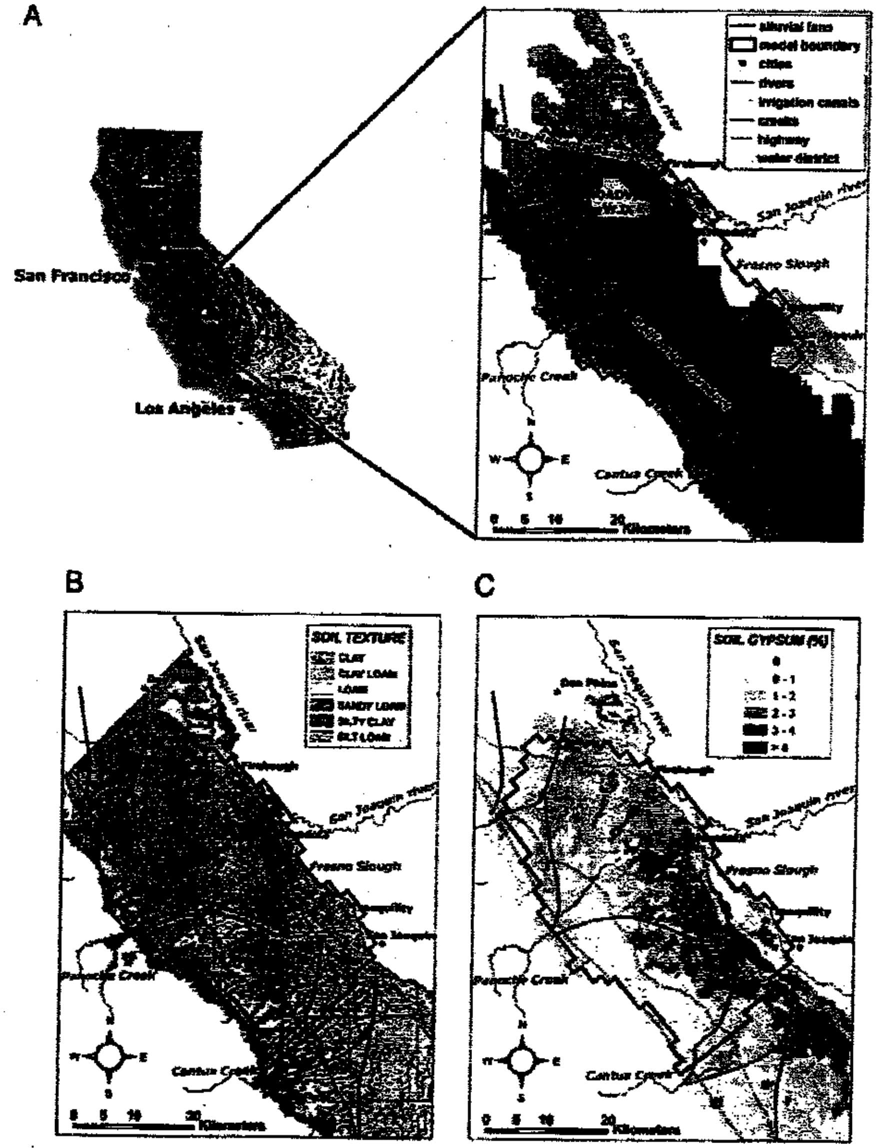

Fig. 1. Overview of the study area. (A) Location of the study area in the western San Joaquin Valley that includes 13 water districts (W.D.). (B) Soil texture map. (C) Soil gypsum contents. The main soil types are clay (52% of the study area), clay loam (35%), loam (4%), and sandy loam (9%). The finer-textured soils are found in the valley trough near the San Joaquin River. These soils have clay contents from 40% to 60%. The clay fraction is dominated by the montmorillonite mineral. Going from east to west, the soils gradually become more coarsely textured. A distinct feature is the sandy loam soils developed in stream deposits of Panoche Creek. Organic matter contents are low. Gypsum is predominantly present in the downslope soils. Soil data are from ref. 14.

Model Environment

The adapted modeling approach is based on the coupling of a soil chemistry module (20) with a regional-scale hydrology model (21) to yield an integrated approach for simulating three-dimensional variably saturated subsurface flow and reactive salt transport (13). The horizontal boundaries of the model domain coincided with the hydrologic boundaries of an earlier regional groundwater flow model (6), defined by the trough of the San Joaquin Valley on the east, the Coast Range foothills in the west, and no-flow boundaries in the north and south of the regional flow domain (Fig. 1A). The model domain was discretized into a regular finite difference grid of 2,960 square cells of 805-m (0.5 mi) side length and 64-ha area, corresponding to a typical field size. In the vertical direction, the model domain extended from the land surface to the top of the Corcoran clay, using 17 layers of increasing thickness from the surface downwards. The total number of active model grid cells was 36,040. Hydrologic flows and salt transport were simulated for a 57-year period, from 1940 to 1997, using annual average boundary conditions and grid cell-specific soil parameters (Figs. 1 B and C and 5). The salinity module included reactions such as cation exchange and precipitation and dissolution of gypsum and calcite (22, 23). By using historical crop acreage and water delivery records for each water district, crops and irrigation amounts were randomly distributed, leading to the annual assignment of a single crop to each grid cell. Other required boundary conditions were needed to quantify

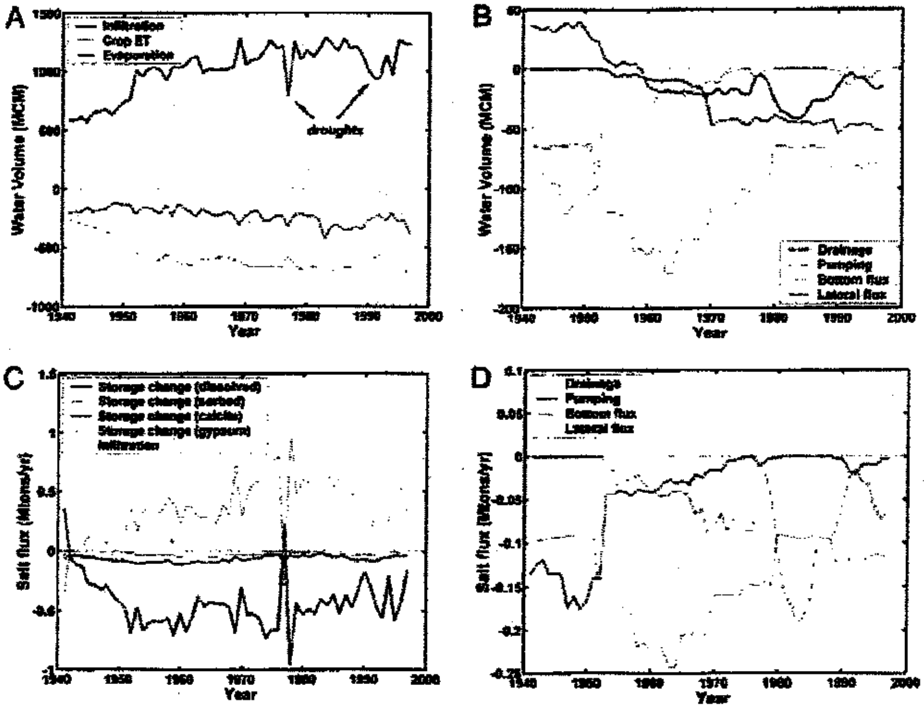

Fig. 2. Simulated water and salt fluxes. (*A* and *B*) Annual-averaged water fluxes for the western San Joaquin Valley [million m^3 (MCM) divide by 1,372 million m^2 (after 1970) to describe fluxes in m/yr; i.e., 1,000 MCM/yr corresponds to 72.8 cm/yr]. (*C* and *D*) Salt balance (Mton/yr) for the western San Joaquin Valley. Positive fluxes designate incoming salt, whereas positive storage terms reflect a decrease in storage. Salt import by infiltration is controlled by ion concentrations of rainfall, surface water, and pumped groundwater. Drainage, bottom flux through Corcoran clay, and lateral salt fluxes toward the San Joaquin Valley trough were generally negative, indicating an export of salts. A major source of dissolved salt was due to gypsum dissolution (green). Respective maxima in 1977 were caused by reduced surface water applications during the drought. The temporary increase in salt export by drainage in the early 1980s was a result of the operation of the Westlands water district drainage system, which was permanently closed down in 1986.

vertical (across Corcoran clay and into deep groundwater) and lateral (toward San Joaquin River) water flow and salt fluxes and exchange between the simulated domain and its surroundings (13), so that an annual salt balance could be estimated. Spatially distributed water flow and salinity reaction and transport parameters were obtained from soil survey data and 242 well logs (more information is available in *Supporting Text*). Hydrological parameter values were either optimized (15, 24) or obtained from existing information (see Tables 1 and 2, which are published as supporting information on the PNAS web site).

Results and Discussion: Salt Balance

Simulation model results included spatial maps of the groundwater table (see Fig. 6, which is published as supporting information on the PNAS web site), drainage flows (15), and groundwater pumping (see Fig. 7, which is published as supporting information on the PNAS web site). as well as regional water fluxes across the domain boundaries, starting in 1940. The hydrologic component simulated the dynamics of the regional variation in water table depths well (Fig. 6), reconstructing the gradual increase in shallow water table area from the 1950s to the 1990s because of increased recharge from irrigated agriculture compared with predevelopment conditions and the shift in irrigation water supply from locally pumped groundwater to imported surface water in the early 1970s.

The steady increases in infiltration (positive) and crop evapotranspiration (negative) reflect the increase in irrigated acreage during the first 30 years (Fig. 2*A*). The decrease in infiltration and increased pumping volumes in the mid-1970s and early 1990s reflect corresponding droughts that coincided with short periods of reduced drainage and deeper groundwater tables (13, 15). Initially, water moved into the simulated domain from the eastern boundary (positive). However, the direction reversed in the early 1970s, with water leaving the region laterally westwards (negative) toward the valley trough (lateral flux in Fig. 2*B*). Deep percolation of water through the Corcoran clay was highest during the 1950–1970 period (Fig. 2*B*), when pumping rates from the confined aquifer were the highest. As surface water was increasingly used, the hydraulic head gradient across the clay layer decreased, thus reducing deep percolation flows. Drainage flows were relatively small, starting in the late 1950s and reaching a maximum when the drainage systems in Westlands water district were operated from 1980 to 1985.

Much of the spatial and temporal dynamics in RZ and groundwater salinity were adequately described with the hydrosalinity model (Fig. 3; see also Fig. 8, which is published as supporting information on the PNAS web site). The salinity dynamics in the shallow groundwater generally followed that of the RZ, indicating that the two systems were closely connected. However, changes in salinity were typically less abrupt in shallow groundwater due to increased mixing of incoming and resident waters in the deeper layers. The relatively slow movement of salts to larger depths indicates that it takes a long time for salts to move into the deeper groundwater. Our model simulations demonstrated that a significant portion of the soil salinity dynamics was controlled by the cycling of soil gypsum through dissolution and precipitation (Fig. 2*C*), as caused by changes in salt leaching with time and soil depth, and soil cation exchange

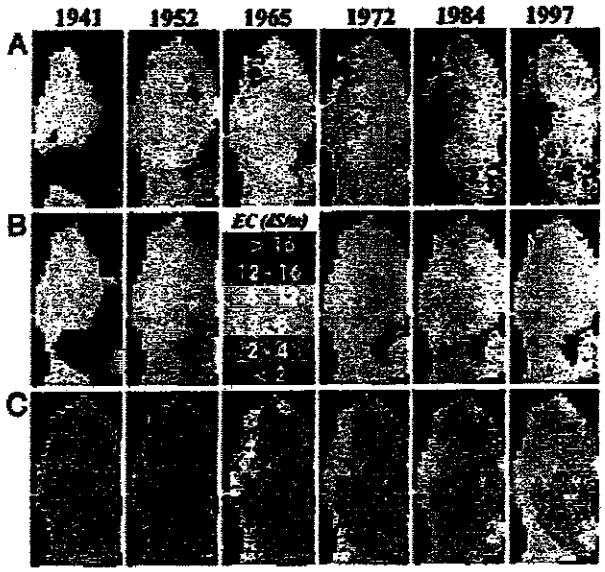

Fig. 3. Temporal changes in the spatial distribution of dissolved salts, expressed by the electrical conductivity (*EC*, dS/m) of the average RZ (0–2 m below the land surface) (*A*), the shallow groundwater system (SGW; 6 m below the land surface) (*B*), and the deep groundwater system (DGW; 20–40 m below the land surface) (*C*). Clearly shown is the initially high RZ salinity in the Panoche-Cantua interfan area (southwestern portion of the study area) and the uniformly low salinity in the DGW. After 10 years of irrigation (1952), part of the initial salinity was leached, resulting in a decrease in RZ salinity. Some of the initial salinity was still present in the SGW. The DGW system on the other hand remained low in salinity. Leaching of RZ salts continued in the initial simulation period, with a sudden decrease in RZ salinity after switching from groundwater to surface water for irrigation in the 1960s. As water levels started to rise in the eastern part of the study area during the 1970s and 1980s, RZ salinity levels increased again due to the simulated increase in irrigation efficiency and capillary rise followed by evaporation as water tables became shallower. This trend of increasing salinity continued through the 1990s. The higher soil salinity in Broadview water district (northern area) was higher than the surrounding areas due to recycling of saline drainage water there.

between Ca and Na (13, 22). This process leads to gypsum dissolution in the upper RZ with subsequent precipitation in the lower RZ and shallow groundwater, as well as high Na and SO_4 concentrations in shallow groundwater (13).

The corresponding soil salinity dynamics over the 57-year period (Fig. 4*A*) are represented by a time series of the number of model grid cells with a RZ average salt concentration (EC_e) of >4 dS/m, which identifies the salt-affected soils. The few measured data points in Fig. 4*A* were derived from aggregating measured soil salinity data reported in 1969 and 1992 soil surveys. Initially, soil salinity was high in 1940 but decreased until ~1975 due to salt leaching when water tables were relatively deep. According to the model, salt leaching occurred in three stages. The initial rate of decrease in soil salinity was low but increased first after 1953 and then even more after 1967, as less-saline imported canal water replaced the locally pumped groundwater as the main source of irrigation water. This general pattern of soil salinity decrease reversed during the 1970s, as continued irrigation raised the water table to levels that caused capillary rise of relatively high-salinity groundwater into the rooting zones. As groundwater levels rose toward the soil surface, less irrigation water was applied to prevent waterlogging. It in turn reduced salt leaching and increased soil salinity. The hydro-salinity model also reconstructed the effects of droughts in 1977 and 1991–1992, resulting in small peaks in soil salinity. The resulting increase in the extent of saline soils was caused by the substitution of surface water for irrigation with more saline groundwater (Fig. 2*B*) and possibly some by widespread land fallowing. Model simulations reproduced the measured increase of area with saline soils after 1970 (Fig. 4*A*), indicating that continued irrigation without changing management practices is not sustainable. The increase in the extent of highly saline soils since 1984 can be seen in Fig. 3*A* (red color in the southern part of the model domain). As a consequence, crop production has been adversely affected, and the land in this area has recently been retired (K. Arroues, personal communication).

When considering the salt-balance equation over an extended period without major hydrologic changes, a pseudoequilibrium will be approached, during which total salt inputs and outputs of the study area will be approximately equal (25). We note that the bottom of the model domain was the top of the Corcoran clay. Salt inflows occur by infiltration of irrigation water and rainfall (Fig. 2*C*), whereas salts may leave the system by the drainage system, groundwater pumping above the Corcoran clay, deep groundwater percolation through the Corcoran clay, and lateral groundwater flows toward the San Joaquin Valley trough (Fig. 2*D*). Moreover, much salt is produced by the net dissolution of gypsum (Fig. 2*C*). When analyzing the simulated annual total salt flows of the study area (Fig. 4*B*), the combined net influx was ~0.3–0.4 million tons (Mton)/yr during the 1950s and 1960s, resulting in an increase in salt storage over time. However, although annual salt accumulations fluctuated later, depending on irrigation water quantity and quality and drought, the average net salt accumulation of the simulated domain appears to be near

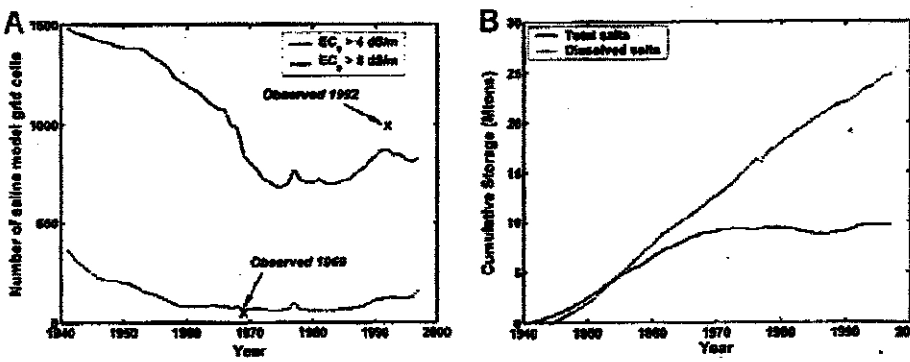

Fig. 4. Simulated salinity changes. (*A*) Time series of number of model grid cells with a simulated average RZ EC_e > 4 dS/m (solid line) and >8 dS/m (dashed line). Symbols correspond to measured data. (*B*) Changes in total salt storage and dissolved salts (in Mton) since 1940.

zero after 1970. The simulated cumulative change in salt storage over the 57-year simulation period (Fig. 4*B*) shows that a pseudoequilibrium developed after 1970, with a total net salt increase between 8 and 10 Mton since 1940. For example, in 1997, the salt input and output values were the same (Fig. 2 *C* and *D*), when the total salt input by irrigation water (0.23 Mton) was equal to salt removal by seepage through the Corcoran clay (0.12 Mton) and lateral groundwater flows toward the San Joaquin Valley trough along the eastern domain boundary (0.11 Mton). This equilibrium occurred despite the fact that much more water entered the study area by irrigation than was removed by vertical, lateral, and drainage flows (Fig. 2 *A* and *B*). Such pseudoequilibrium in salt storage can only occur if the salinity of the water inputs is much lower than that of the outputs. Indeed, simulations confirmed it to be the case. Although the salt-balance results indicate that crop productivity can be maintained, sustainability is threatened in two ways. First, the storage of dissolved salts has increased continuously since 1945 at an average rate of ≈0.5 Mton/yr (Fig. 4*B*) due to gypsum dissolution (Fig. 2*C*). Second, the simulations also showed that the deeper aquifers below the Corcoran clay accumulate salt, thereby degrading deep groundwater quality. By using 1997 again as an example, flow through the Corcoran clay at a rate of 80 million m^3/yr (Fig. 2*B*) with a salt load of 0.12 Mton corresponds to an average salt concentration of 1,150 mg/liter (ppm) of the groundwater percolating through the Corcoran clay into the deeper groundwater. This process of salinization of the deeper groundwater bodies may take many decades or longer (26), thus making the deeper groundwater less suitable for drinking or irrigation water purposes and putting the sustainability of current irrigation practices into question. Indications (27) are that reversal of this process by reducing salt loads in the future may take even longer, because of diffusion control of low-permeable finer-grained aquifer materials.

We conclude that the salinization issues are critical to the sustainability of irrigated agriculture in the San Joaquin Valley and similarly probably to many other areas of the world with relatively closed groundwater systems. Our detailed historic simulations of soil and groundwater salinity in the San Joaquin Valley suggest that irrigation may not be sustainable. Future work should assess the robustness of these conclusions by means of a parameter sensitivity analysis and further field testing of the model simulations (see *Supporting Text* for further discussion). Although not considered in this study, accumulation of boron and selenium in soils of the San Joaquin Valley pose an additional threat to the sustainability of agriculture (28, 29).

We thank HydroGeologic Inc. for providing us with a beta version of the MODHMS model and Dr. Don L. Suarez (George E. Brown, Jr., Salinity Laboratory) for providing us with the UNSATCHEM software. Our work has greatly benefited from insights by Kerry Arroues (Natural Resources Conservation Service) regarding soil salinization in the San Joaquin Valley. We thank Drs. Peter Vaughan, Dennis Corwin (both from George E. Brown, Jr., Salinity Laboratory), and Jim Ayars (U.S. Department of Agriculture Water Management Laboratory) for providing us with the irrigation/drainage and groundwater data for the Broadview Water District, without which some of the evaluation results would not have been possible. We also thank Gordon Huntington for providing us with the 1969 soil salinity map and Charles Brush (U.S. Geological Survey) for providing us with water delivery data. This work was supported by U.S. Department of Agriculture Funds for Rural America Project 97-362000-5263 and by the U.S. Bureau of Reclamation. J.A.V. was supported by the Earth Life Sciences and Research Council with financial aid from the Netherlands Organization for Scientific Research.

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REGIONAL GEOLOGY SECTION
SACRAMENTO, CALIFORNIA

June 28, 2002

MEMORANDUM TO THE TECHNICAL FILES

FROM: Robert L. Turner, Geologist

SUBJECT: Seepage Investigations Along the San Luis Canal/California Aqueduct at Mile 89.5 (approximate Station 1040+00) Near Eagle Field Road - Central Valley Project, California

Introduction

During the period June 3 through June 25, 2002, eight observation/sampling wells were installed by Reclamation's Drill Crew along two profiles perpendicular to the San Luis Canal/California Aqueduct at Miles 89.5 and 89.7. Figure 1 shows the general location of these sites and the layout of these wells. Five wells were installed along the north profile (Profile A) and three along the south profile (Profile B). An existing Department of Water Resources (DWR) Right of Way (ROW) well was incorporated into the southern profile as ROW-4B. Profile A was located to transect a known seepage area at Mile 89.5, while Profile B, located at Mile 89.7, was to serve as a test control area away from the seepage. A ninth well was proposed for the far east side of Profile B, but crops and irrigation prevented access. This well will be installed in October 2002.

The purpose of these wells is to determine if canal seepage in this area significantly contributes to the amount of drainage water leaving Grasslands Water District. Data obtained from the drilling and observation wells provided the following:

1. Subsurface geology.
2. Subsurface moisture content of soils above the water table.
3. Groundwater flow direction.
4. Groundwater gradient.
5. Is there a groundwater mound beneath the canal?
6. Are there water quality differences between the upslope and downslope groundwater caused by the inflow of canal water?

Background

Water districts downslope (east and northeast) of the San Luis Canal/California Aqueduct are concerned about leakage from the canal in the vicinity of Mile 89.5. Most important, they believe that seepage visible at the surface adjacent to the toe of the left embankment of the canal just north of Eagle Field Road is indicative of greater vertical leakage through the lining into the groundwater. Recent underwater inspection of this section of the canal showed broken and displaced lining. The groundwater gradient is generally to the east and northeast in this area and the concern is that the leakage from the canal is adding to the volume of subsurface drainage water in the Grasslands Drainage Area (GDA). The GDA is under severe limitation regarding the amount of subsurface drainage water that can be discharged from the area.

There are no irrigation or domestic wells in the west Eagle Field Road area. The canal at Mile 89.5 is in elevated cut/fill, with the right (west) side of the canal in cut and the left (east) side in fill. Invert is in original ground. Eleven Canal Right-Of-Way observation wells installed years ago by the Department of Water Resources (DWR) north of Mile 89.5 and adjacent to and at the base (original ground) of the canal were located in the field on September 27, 2001. Eight were dry at depths below ground level shallower than 38 feet, two wells were locked, and the remaining one had groundwater at 39 feet below ground. A DWR groundwater elevation map for spring 1999 does not show groundwater elevations for the study area but does show the 140-foot elevation contour about three miles to the northeast.

The seepage area of concern is just north of Eagle Field Road on the left (northeast toe) of the canal embankment (see Figure 1) in an area of some past land subsidence due to hydrocompaction. The seepage area encompasses an area on the left canal embankment of about 20 feet perpendicular to the canal and about 200 feet long. The slope is heavily vegetated due to the seepage. On June 3, 2002, a small seep of clear water flowing at about one gal/min is present about halfway up the slope. During the drilling of the new observation wells, it was discovered that the ponded seepage and the associated vegetation (at the toe of the embankment) lies above an old asphalt roadway. This asphalt surface prevents the local infiltration of seepage water. The water level in the ponded area fluctuated about three-inches daily (nearly drying the area in the late afternoon) in response to evaporation during the hot daytime hours.

DWR has installed numerous pressure grout wells on the inside left canal operating road in an attempt to stop the seepage but has been unsuccessful in these attempts. There are several other sections to the north that have also been grouted, and most of those attempts appear to have been successful.

DWR conducted a ponding test of Pool 14 from January 1 to February 18, 2002. Some of the data are summarized in Table 1 and the total daily gain/loss for the pool is shown graphically in Figure 2. Pool 14 is approximately 10 miles long. The canal gained a total of 3,900 acre-feet of water during that period of time. DWR believes that questionable instrument accuracy may have contributed to the results noted in the test.

Drilling Procedures and Well Data

The eight wells were drilled by Reclamation's Mobile B-90 drill rig using the hollow-stem flight-auger, dry coring system. The core samples from each well were geologically logged by an on-site geologist and samples were collected for lab analyses of soil properties, including moisture content. Wells were drilled about ten feet below the water table and completed with two-inch diameter PVC pipe with the bottom ten feet perforated with 0.020-inch factory slots. A sand pack was placed opposite the perforated interval and the upper portion of each well above the sand pack was sealed with bentonite pellets. Each well was pumped for development upon completion and the water was tested for electrical conductivity (EC), an indicator of total dissolved solids. All wells except ROW-4B pumped dry within two minutes and groundwater was a light brown color that did not clear up with successive pumping. ROW-4B was manually bailed because no pump was available to fit in the 1-1/2-inch diameter well. Table 2 shows the well completion information and groundwater sample electrical conductivity for each well. The geologic logs are not completed at the present time.

Results of Drilling Investigations

The results of the drilling investigations are discussed below:

1. **Subsurface geology** - Geologic logs for the eight new wells are attached to this memo. Cores recovered in this drilling program consisted of predominantly sandy, silty clay with occasional thin sand lenses overlying predominantly sands with occasional thin clay layers. The sands were generally encountered at about 10 feet above the water table. Well completion data for the DWR ROW well, ROW-4B, was not available. Canal as-built construction geology maps described the subsurface soils in the Mile 89.5 area to be silty clay to clayey sand.

2. **Subsurface saturation of soils above the water table** - Samples obtained during drilling at each well shows most soil above the water table was only slightly moist to moist. There were no saturated zones above the water table. The soils encountered in the well in the surface seepage area, OW-02-4A, showed that the subsurface was just slightly moist until 36 feet below ground.

3. **Groundwater flow direction** - Each well was surveyed for elevation and location by MP-222 using a local coordinate system. These values are shown in Table 2. Groundwater level measurements are also shown in Table 2. Elevations show groundwater flow direction to be to the east, generally coinciding with the ground slope direction.

4. **Groundwater gradient** - By using the groundwater elevations for OW-02-1A, -1B, and -5A, the groundwater gradient across the study area calculates to be about 35 feet per mile to the east. This assumes that the wells farthest west and east reflect true groundwater

elevations without the influence of the canal mound. The Department of Water Resources (DWR) groundwater map for spring 1999 does not show elevations for the study area. However, it does place the 140-foot elevation contour about three miles to the northeast, or an average groundwater gradient of about 50 feet per mile, assuming the same aquifer.

5. **Is there is a groundwater mound beneath the canal?** - Groundwater elevations show higher groundwater levels beneath the canal than east or west of the canal, indicating that a groundwater mound is present beneath the canal under both Profiles A and B (Figure 4). The mound is more pronounced beneath Profile B, where no visual seepage is indicated, than under Profile A, where there is a seepage area and water ponding east of the canal. This pronounced mound is most likely due to the low permeability soils at this location that retard horizontal and vertical migration of canal seepage water. The soils at Profile A have a higher permeability resulting in a less pronounced groundwater mound.

6. **Are there water quality differences between the upslope and downslope groundwater caused by the inflow of canal water?** - Each well except ROW-4B was pumped to obtain a groundwater sample. Each well pumped dry within about two minutes and could not sustain a flow of about two gal/min for more than a minute. A bailer was used to obtain a sample from ROW-4B due to the small diameter of the casing. Table 2 and Figure 4 show the results of the groundwater electrical conductivity (EC) measurements for all wells and the canal water. EC is an indicator of total dissolved solids. The EC of the canal water was 490 uS/cm.

The EC of the two up-gradient wells (OW-02-1A and -1B) was 1,320 and 2,650 uS/cm, respectively. It is assumed that the higher EC upslope is indicative of the local groundwater absent canal seepage. The upslope well OW-02-1A has an EC lower than the other upslope well OW-02-1B; this may be due to dilution of the groundwater by the deep percolation of applied canal water used to irrigate the land to the west of OW-02-1A. EC for wells on the canal's Right-of-Way roads ranged from 510 to 560 uS/cm (similar to the EC for canal water of 490 uS/cm), indicating that the canal water is leaking into the shallow groundwater aquifer and diluting the water.

The EC for ROW-4B (1,665 uS/cm) is anomalous compared to the other wells right next to and downslope of the canal. The well perforations are unknown for this well. Another well completed in a manner similar to the other OW wells is scheduled to be drilled at a later date.

<u>Conclusions</u>

Based upon the results stated above, we conclude that the canal is leaking in the areas both north and south of Eagle Field Road, and this seepage is contributing to the groundwater flow to the east. The ponded water in the seepage area appears to be the direct result of canal losses through a horizontal conduit above ground level. The ponding is enhanced by the presence of an old asphalt surface adjacent to the canal beneath the catchment area that prevents infiltration. The seepage is not indicative of vertical leakage from the canal to the groundwater.

To estimate the volume of vertical seepage from the canal would require estimates for many unknowns. Among these would be the following:

1. The condition of the canal concrete lining - Past underwater inspection of the canal concrete lining shows it intact in some places and open in others, resulting in large differences in canal loss to the soil interface.

2. The transmissivity of the soils beneath and adjacent to the canal - Near-surface soils at Mile 89.5 and 87.5 contain a high percentage of fines, whereas, near-surface soils at Station 1033, located about 0.2 miles to the north, consist of a high percentage of sand and gravels deposited by Laguna Seca Creek.

3. The determination of groundwater levels under the canal at many locations - For example, seepage in the Mile 89.5 area is free-fall to the water table; this condition would maximize the vertical gradient for recharge. Canal water and groundwater are in continuity at Mile 87.5 along Profile B which would greatly minimize the gradient.

4. The length of the canal that is leaking.

We can use the following assumptions to approximate canal leakage in this area:

- Canal length of one mile.

- Transmissivity of from 10^2 to 10^3 ft^2/day (reasonable for the clayey soils).

- Groundwater gradient of about 35 ft/mile.

- All groundwater moving to the east is from canal leakage. This assumption ignores groundwater subinflow from the west, an unknown quantity, and the deep percolation of applied irrigation water.

Using the above assumptions, leakage would range from about 3,500 to 35,000 cubic feet per day (29 to 290 acre-feet per year) per mile length of canal.

Liz Partridge (TO-431) has researched the predicted losses for the canal and these are summarized below:

1. The Designer's Operating Criteria for the canal states that the seepage losses are estimated to be 100 cfs for the 102 miles of the canal. If we assume that the District is influence by

seepage from about 10 miles of canal, this is roughly equal to 7,100 acre-feet per year, or about 710 acre-feet per mile length of canal.

2. The Technical Report of Design and Construction for the San Luis Unit assumes that the seepage rate would be .07 cubic feet per foot of wetted surface per day. This is roughly equivalent to 5,730 acre-feet per year for the 10-mile stretch, or about 570 acre-feet per year.

Robert L. Turner, Geologist

Noted: Joel F. Sturm, Head, Geology Section — 9/17/02 Date

Noted: Charles L. Howard, Regional Geologist — 9-17-02 Date

Attachments

cc: TO-431 (Partridge), SCCAO-400 (Buelna), MP-400, Central Files
(w/att to each)

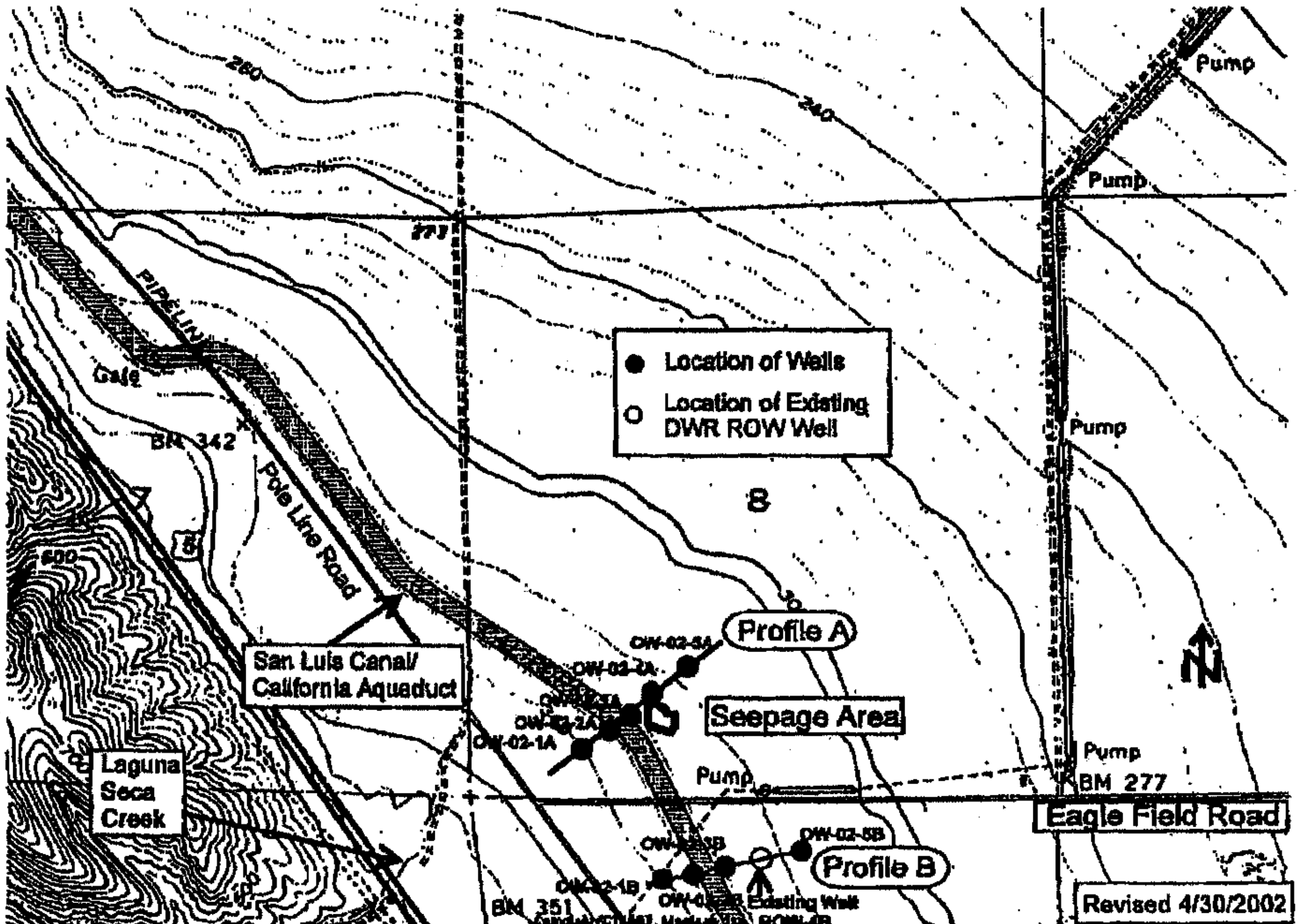

Figure 1: Eagle Field Road Seepage - General Location of Wells Along the San Luis Canal/California Aqueduct Near Mile 89.5

Table 1: Pool 14 Ponding Test by DWR - Jan. 1 thru Feb. 18, 2002 (Partial results)

DATE	Pool Elevation	Surface Area	Pool Storage	Storage Change	Pool Losses	Pool Losses	Accu.Losses
Jan. 1	329.70	7569900	2804	-53	+146	146	146
2	330.27	7667400	2902	98	+270	270	416
3	330.38	7686300	2921	19	+142	142	558
4	330.60	7723900	2959	38	+302	302	860
5	330.04	7628100	2862	-97	+117	117	977
6	329.56	7546000	2780	-82	+332	332	1309
7	330.05	7629800	2864	84	+382	382	1691
8	329.78	7583600	2817	-47	+115	115	1806
9	329.64	7559700	2793	-24	+183	183	1989
10	329.80	7587000	2821	28	-60	-60	1929
11	330.24	7662300	2897	76	+319	319	2248
12	329.66	7563100	2797	-100	+12	12	2260
13	329.98	7617800	2851	54	+249	249	2509
14	330.13	7643500	2878	27	+152	152	2661
15	330.29	7670900	2906	28	-35	-35	2626
16	330.49	7705100	2940	34	+157	157	2783
17	330.06	7631500	2866	-74	-14	-14	2769
18	329.92	7607600	2841	-25	+144	144	2913
19	329.70	7569900	2804	-37	+15	15	2928
20	330.01	7623000	2857	53	+159	159	3087
21	330.27	7667400	2902	45	+79	79	3166
22	329.86	7597300	2831	-71	-23	-23	3143
23	330.12	7641800	2876	45	+56	56	3199
24	329.65	7561400	2795	-81	-49	-49	3150
25	329.94	7611000	2845	50	+54	54	3204
26	330.14	7645200	2879	34	+187	187	3391
27	330.74	7747900	2984	105	+226	226	3617
28	330.52	7710200	2946	-38	+28	28	3645
29	330.34	7679400	2914	-32	+154	154	3799
30	330.47	7701700	2937	23	+127	127	3926
31	330.20	7655500	2890	-47	+44	44	3970
Feb. 1	330.61	7725600	2961	71	+267	267	4237
2	330.62	7727300	2963	2	+85	85	4322
3	330.54	7713600	2949	-14	+133	133	4455
4	329.74	7576800	2811	-138	-93	-93	4362
5	330.06	7631500	2866	55	+228	228	4590
6	330.16	7648600	2883	17	+159	159	4749
7	330.06	7631500	2866	-17	-2	-2	4747
8	330.56	7717100	2952	86	+218	218	4965
9	330.36	7682800	2918	-34	-324	-324	4641
10	330.26	7665700	2900	-18	-222	-222	4419
11	330.26	7665700	2900	0	-26	-26	4393
12	330.46	7700000	2935	35	-14	-14	4379
13	330.46	7700000	2935	0	+123	123	4502
14	330.66	7734200	2970	35	-6	-6	4496
15	331.16	7819700	3057	87	-30	-30	4466
16	331.16	7819700	3057	0	-98	-98	4368
17	330.96	7785500	3022	-35	-328	-328	4040
18	330.96	7785500	3022	0	-136	-136	3904

Pool Evaporation = Evaporation in LBDD weather station pan X pool surfTotal Gain = 3,970
Days with rain are not used for test, because inflow from drain inlets is not measured. Known data will be shown.
Daily pool losses are for the time ending at 2400 hours. Plus (+) is gain, and minus (-) is loss.

Pacheco W.D. meter 89.67L'B' not working 1/1 - 1/31/02. San Luis W.D. meter 92.73L'B' not working 1/1 - 2/16/02

*No data available.
**These days are based on hourly flow average.

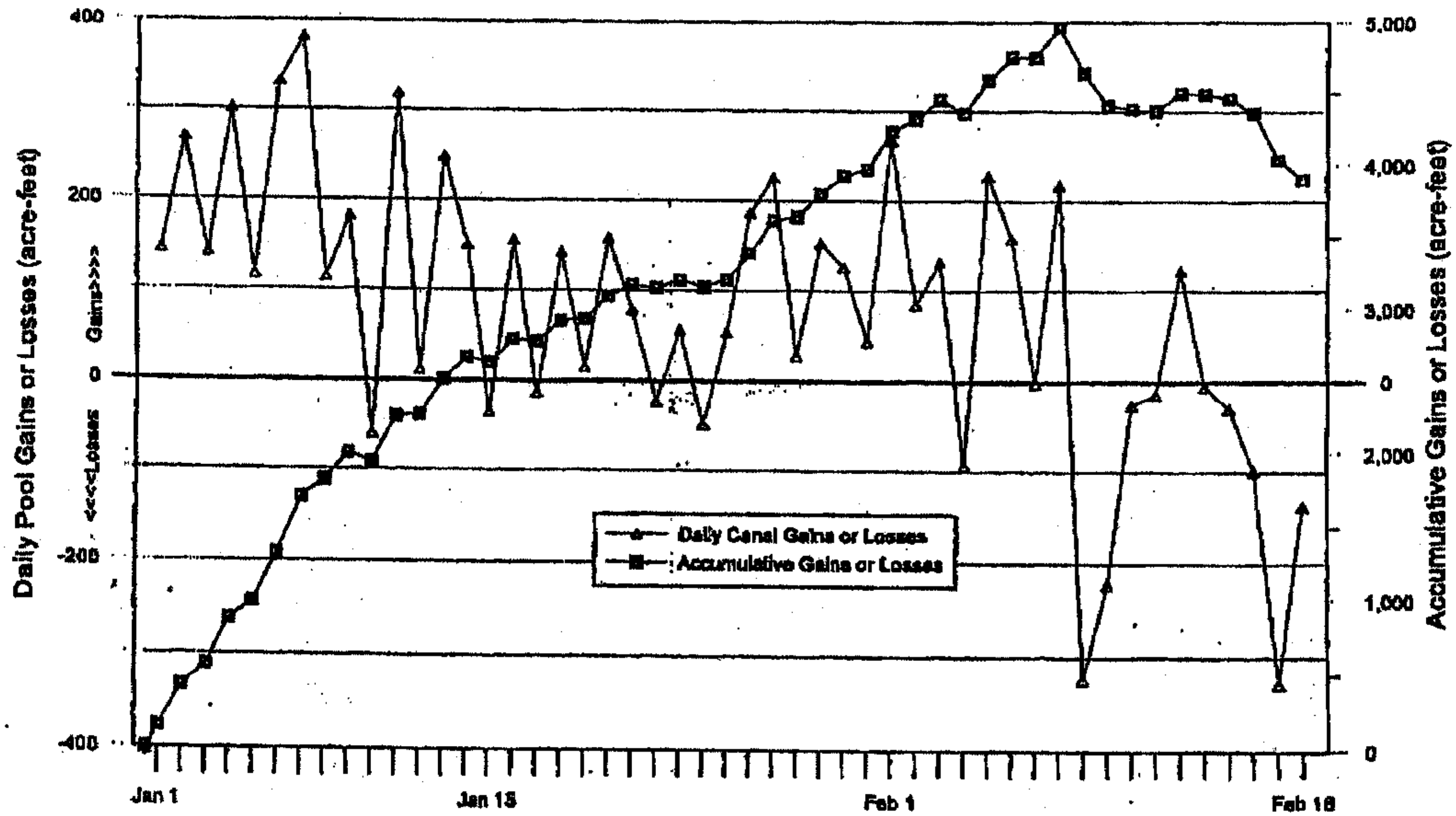

Figure 2: San Luis Canal/California Aqueduct - Pool 14 Test - January to February 2002

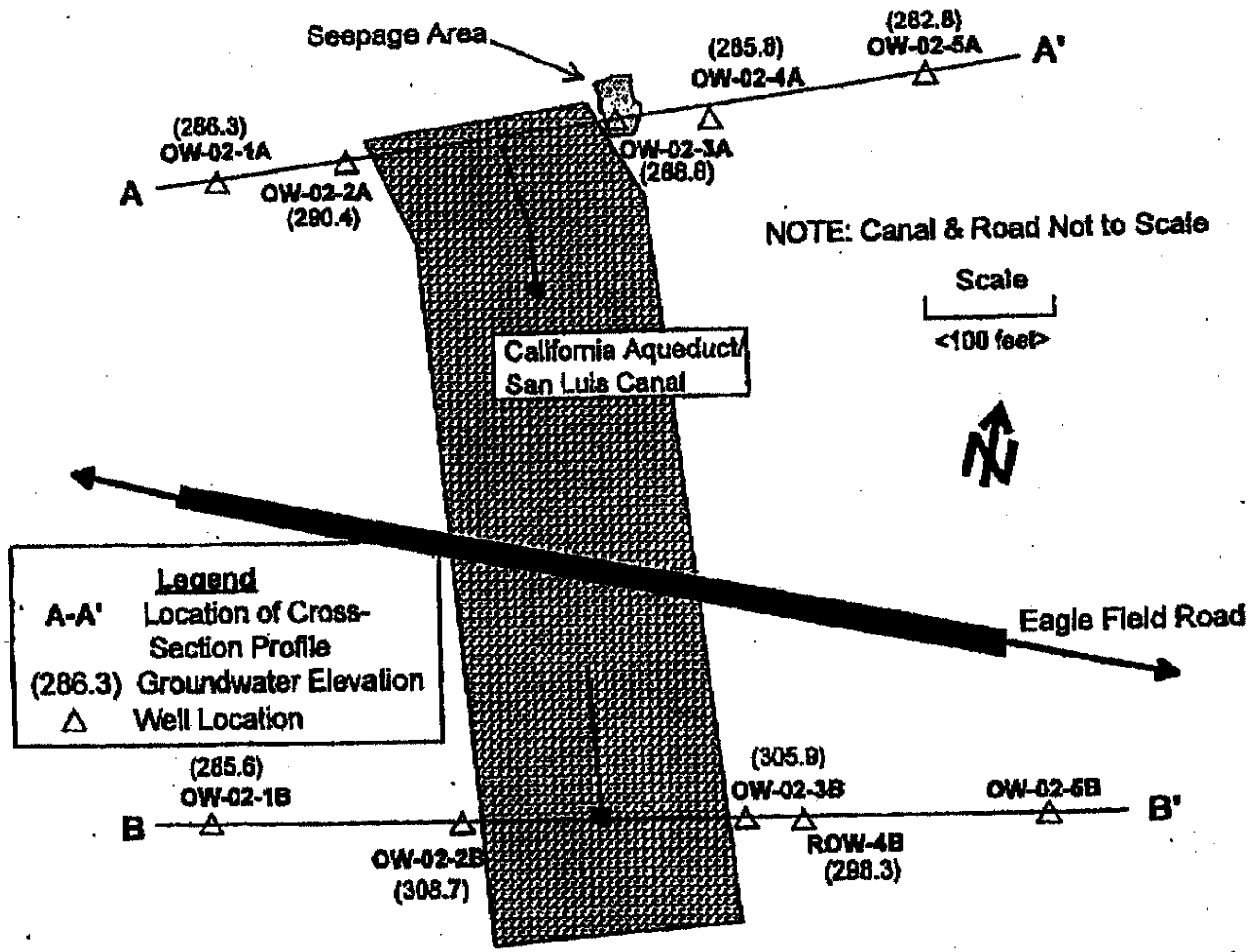

Figure 3: Eagle Field Road - Location of Wells and Groundwater Elevations

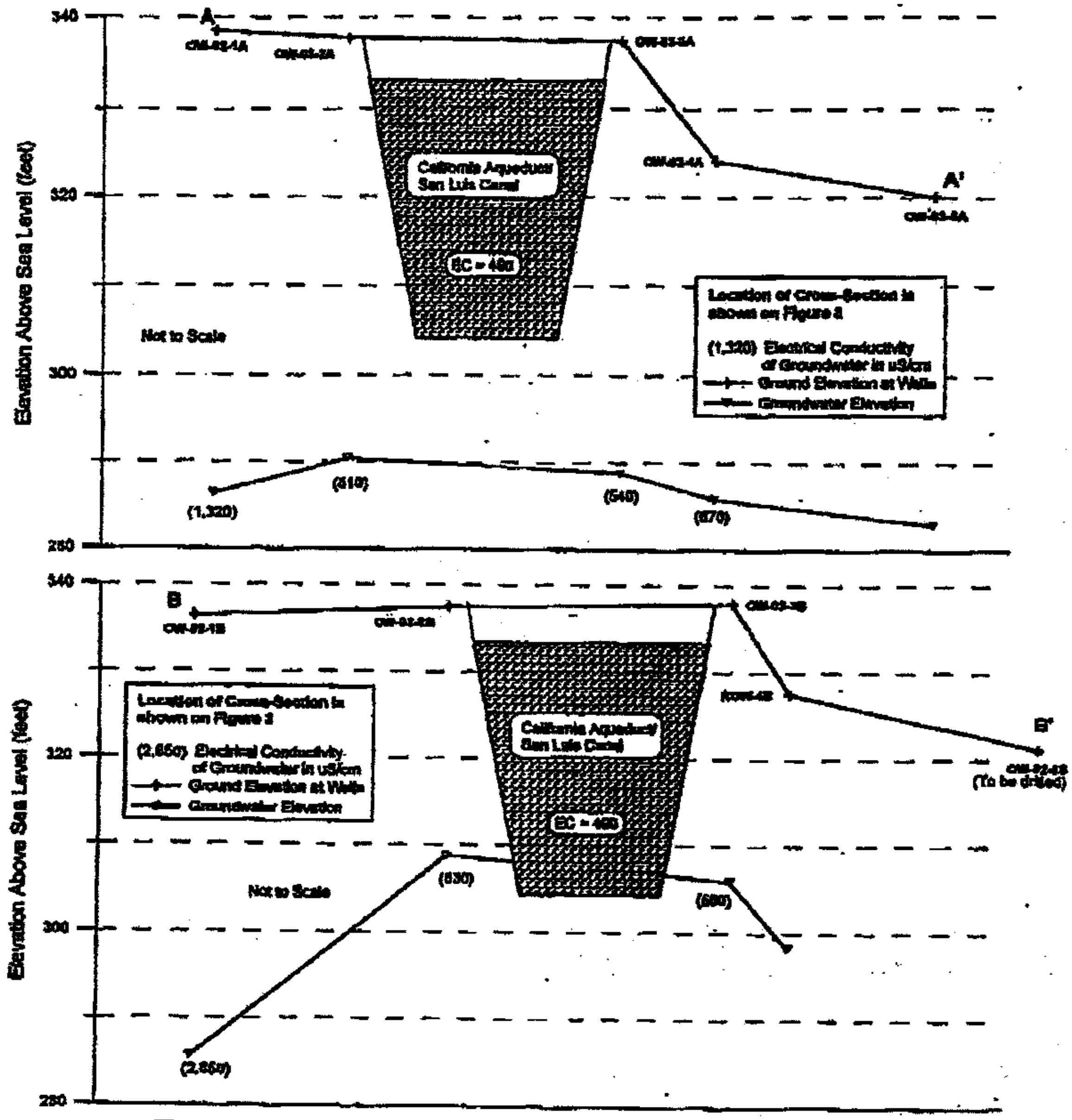

Figure 4: Eagle Field Road - Cross-Sections thru A-A' and B-B'

Table 2 - Eagle Field Road/Grasslands Seepage Well Data

Well I.D.	Northerly [a]	Easterly [a]	Total Depth	Perforations [b]	Ground Elevation [a]	Depth to Groundwater [c]	Groundwater Elevation	Electrical Conductivity [d]
	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(feet)	(uS/cm)
				<< Profile A >>				
OW-02-1A	9652.9	5114.4	65.0	53.8 - 63.8	338.6	52.1	286.5	1320
OW-02-2A	9617.9	5011.8	60.0	48.7 - 58.7	337.8	47.0	290.8	510
OW-02-3A	9547.4	4799.2	59.0	49.0 - 59.0	337.5	48.4	289.1	538
OW-02-4A	9548.1	4725.7	49.3	38.7 - 48.7	324.1	37.9	286.2	670
OW-02-5A	9470.9	4557.7	49.5	39.5 - 49.5	320.0	36.9	283.1	695
				<< Profile B >>				
OW-02-1B	10874.8	5128.2	60.0	49.0 - 59.0	336.5	50.6	285.9	2650
OW-02-2B	10880.6	4930.9	40.0	29.3 - 39.3	337.5	28.6	308.9	530
OW-02-3B	10880.3	4709.5	40.0	29.3 - 39.3	337.9	31.4	306.5	560
ROW-4B [e]	10884.0	4664.8	45.3 [f]	[e]	327.5	28.1	299.4	1,665
OW-02-5B	10879.6	4475.9			321.2		Not Drilled	

[a] From a field survey by MP-222 using a local coordinate system.

[b] All wells (except previously existing ROW-4B) drilled to approximately 10 feet below water table and completed with 2-inch PVC pipe, with the lower 10 feet 0.020-inch factory-slotted PVC. Sand pack installed opposite perforated intervals and bentonite pellets installed above sand pack to surface.

[c] From ground surface. Wells OW-2A, -3A, -2B and 3B are on top of canal embankment adjacent to ROW Road.

[d] An indicator of total dissolved solids. Electrical conductivity of the canal water is 490 uS/cm.

[e] An existing California Department of Water Resources well with no available completion data.

[f] Measured in the field